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Phenomenology of High-Energy Collisions

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Abstract

This is the final report of a Laboratory-Directed Research and Development (LDRD) project at the Los Alamos National Laboratory (LANL).

Fundamental theoretical issues of nuclear and high-energy physics have been examined with the goal of determining observable phenomena that would help determine the existence of a quark-gluon plasma. A light-cone approach for proton-nucleus and nucleus-nucleus collisions, formulated in the target rest frame and relying on a particular description of the gluon density in nuclei, was developed for this purpose. The theory may be decisively tested at new experimental facilities. Predictions are thus being made that can be tested at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory and the Large Hadron Collider (LHC) in Europe scheduled for completion in 2005.

1. Background and Research Objectives

It is the dream of the current generation of physicists to find a new state of matter, the so-called quark gluon plasma, in which quarks and gluons are no longer confined in protons and neutrons but can propagate freely. Closely related to this field are the challenges of examining gluons with very small velocity inside a nucleus. We explored fundamental theoretical issues of nuclear and high-energy physics with the goal of determining what observable phenomena would allow definite conclusions about the existence of a quark-gluon plasma.

The project, therefore, made theoretical predictions for physics at RHIC using a new technique based on the color-dipole model. These are predictions for specific quantum chromodynamic processes that underlie (for example) dilepton production, a main reaction that experimentalists will use to determine if a quark-gluon plasma was produced in the collision of two relativistic heavy ions. The theoretical predictions are important for measurement of the quark-gluon plasma because experimenters can use them to calibrate their techniques and develop confidence in the theory for other purposes.

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2. Importance to LANL's Science and Technology Base and National R&D Needs

This project supports this DOE mission, and it supports the objective identified in the University of California Contract with the DOE: Enhance and nurture a strong science base in support of NASA strategic objectives. This project supports the basic scientific mission of the DOE. The DOE manages a number of accelerator facilities, one of which is the relativistic heavy ion collider (RHIC) at Brookhaven National Laboratory. The main goal of this accelerator is to produce the quark-gluon plasma in the laboratory.

3. Scientific Approach and Accomplishments

During the past year, we studied a light-cone Green's function approach to multiple scattering, which incorporates the correct quantum mechanical treatment of a finite coherence length. The Green's function approach is formulated in the target rest frame and based on a decomposition of the projectile into partonic configurations with well-defined separations in impact parameter space. Following the spirit of Glauber theory, all free parameters are fitted to scattering off a proton target; nuclear effects are then calculated without introducing any new parameters. Main input to our formulae is the cross section for scattering a colorless quark-antiquark-dipole off a nucleon, for which we use a phenomenological parameterization.

Since this parameterization is fitted only to deep inelastic scattering (DIS) data, we also demonstrated the applicability of our approach to Drell-Yan dilepton production [1] and to hadroproduction of open charm and bottom [2]. The latter process is especially sensitive to gluon dynamics. It was shown that this theory performs exactly as expected, and is therefore poised to make predictions in the more complicated case of proton-nucleus and nucleus-nucleus collisions. In addition, we also investigated the relation between the dipole approach and the conventional parton model [1,2], and generalized the theory to W and Z boson production [3].

This approach provides unique advantages for the study of several key questions related to RHIC physics goals and recent data:

The depletion of large transverse momentum hadron spectra requires a trustable calculation of the Cronin effect for reliable interpretation. In the Green's function technique, the Cronin effect is calculated in a parameter-free way. We also obtained a good description of shadowing data for

DIS and calculated shadowing for Drell-Yan dileptons in proton-nucleus and in nucleus-nucleus collisions. In addition, we predict much larger shadowing for valence than for sea quarks [4].

Since the limit of infinite coherence length is not reached at present collider energies, it is essential to include the correct, finite coherence length in the calculation. To our best knowledge, the Green's function technique is the only approach where this is done.

During the past few years, our approach has developed into a sound phenomenology of coherence effects at RHIC and LHC. Most importantly, it combines a calculational framework for nuclear effects in high-energy collisions with an intuitive understanding of the underlying physical mechanisms.

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